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Mitigate water-side fouling in fire tube boilers

One of the most important pieces of equipment used in many industries is the fire tube boiler. However, these machines are vulnerable to issues caused by fouling. With the passage of time, deposits accumulate on two sides of the heat transfer surfaces as a result of various factors. Water-side fouling occurs on the outer surfaces of the furnace and tubes and is composed of many chemical deposits. These deposits may consist of carbonate hardness, sulfates, silicates, phosphates, hydroxides, oxides, sulfides, silica, mud and debris. Fire-side fouling is formed on the internal surfaces of furnaces and tubes due to combustion products.[1]

The cleaning of the fire side in fire tube boilers is easier than the cleaning of the water side. The fire side offers ease of access via the front and rear doors. Furthermore, a variety of tools and methods can be used to achieve the cleaning. The cleaning of the water side is more complicated to carry out, primarily due to a lack of research and investigation.

This article is intended to help the reader understand the various parameters that increase the rate of water-side fouling. It also provides a review of the most famous water-side fouling mitigation methods and suggests effective solutions for decreasing the water-side fouling rate by considering design and operating factors.

Composition of water-side fouling. The composition of the deposit layers on the heat transfer surfaces close to the water side of fire tube boilers is usually due to a number of reasons. According to Epstein,[2] fouling can be classified into the following categories:

- **Crystallization fouling:** Solidification or precipitation of salts from super-saturated solutions
- **Particulate fouling:** Deposition of suspended solids particles (dirt, silt, clay, rust)
- **Chemical reaction fouling:** Deposition resulting from chemical reactions between reactants
- **Corrosion fouling:** Deposition produced by reactions between reactants and the metal surface.

All of these fouling types can be found in deposit layers on the water side of a fire tube boiler.[3] **FIG. 1** shows the deposits on two samples taken from a scrapped fire tube boiler in a 12-tph saturated steam unit in an Egyptian refinery. The following is an analysis of the results of the fouling composition on the water side for the two samples in **FIG. 1:**

- **Physical properties:** Brown solid crystalline that is solely soluble in water-diluted and concentrated acids

FIG. 1. Two fouling deposit specimens taken from a scrapped fire tube boiler.

- **Chemical composition:** Calcium: 26.5%, silicate: 35.1%, mud deposits: 25%, magnesium: 3.1%, iron: 3.7%, sodium: 6.9% and manganese: 0.7%.

The fouling complexity and the difficulty of accessibility (due to the manufacturer's compact fire tube boiler design) make the cleaning of the water side a difficult venture. Various mitigation methods can help with this issue, as explained in the following subsections.

Mitigation methods for water-side fouling. Steinhagen *et al.*[4] classified the main methodologies for the mitigation of fouling in industrial heat exchangers in terms of chemical, mechanical and physical methods. In addition to these methods, advanced methods can be achieved with the use of nanotechnology.

Chemical cleaning. Several chemicals can be used for industrial cleaning, as shown in **TABLE 1.** However, there are several disadvantages to these chemical cleaning methods. Chemical agents may contain substances that are potentially harmful for handling or disposal to the environment, such as chlorine, hypochlorite, polyphosphate, coagulants, etc. Also, the compatibility of the inhibitor chemistry and the metallurgy of the equipment must be ascertained to avoid corrosion or cracking of the internal components of the boiler.

Nanotechnology for cleaning. The most common nanotechnology method is enhanced filtration, using nanoparticles. Chun Su *et al.*[5] experimentally studied the performance of cellulose acetate and mixed cellulose ester micro-filters enhanced with TiO_2 nanoparticles. The results showed higher filtration effectiveness than the ordinary cellulose acetate membranes for fouling reduction.

In spite of high filtration performance with nanotechnology, the associated high operational costs are a barrier to mass pro-

TABLE. 1 Chemical cleaning methods for fouling deposits[4]

Deposit	Cleaning method
Calcium sulfate	Boil with Na_2CO_3 solution treated with inhibited acid
Calcium carbonate	Inhibited acid
Magnesium hydroxide	Inhibited acid
Calcium phosphate sludge	Inhibited acid
Magnesium silicate	Inhibited acid, small percentage of hydrofluoric acid
Sodium aluminum silicate	Hydrofluoric acid
Ferric oxide (Fe_2O_3)	Inhibited acid or ammoniated critic acid
Ferrous oxide (FeO)	Inhibited acid or ammoniated critic acid; add 0.25%–0.5% stannous chloride for protection against ferric ion attack; ammoniated EDTA
Copper	Ammoniated EDTA, ammoniated bromate

duction on an industrial scale. As shown by Olvera *et al.*,[6] the economic feasibility of nanotechnology for water treatment applications has the following disadvantages:

- High average cost of nanofiltration devices and low production capacity
- Disassociation of scientific research with manufacturing
- Need for more studies on the effects of nanoparticles on the environment.

Mechanical cleaning. Research in mechanical cleaning concerns the cleaning of deposits from the tube inner surfaces, such as those used in the tube bundles of shell-and-tube heat exchangers. As explained by Bott,[7] the different online mechanical cleaning methods are as follows:

- **Circulation of sponge rubber balls:** Applicable only to flow through the insides of the tubes for the maintenance of the condenser. Also used with some success to reduce scale formation in a multi-stage flash desalination plant.
- **Brush and cage systems:** Similar to the sponge rubber ball technology. Systems are fabricated from suitable metal wires or polymer filaments and passed through the tubes by liquid flow for the prevention of deposit accumulation on the insides of the tubes.
- **Air injection (rumbling):** Using slugs of air in liquid flows could create a two-phase mixture with high turbidity in the regions near the surfaces of heat transfer. This technique could be applied to areas where accessibility is difficult—for example, the shell side of shell-and-tube heat exchangers.
- **Hydroblasting:** Accomplished by using high-pressure water jets. The International Organization for Standardization[8] classified the cleaning pressures as low-pressure water cleaning (LPWC), a cleaning performed at pressures less than 34 MPa; and high-pressure water cleaning (HPWC), a cleaning performed at pressures from 34 MPa–70 MPa.

Two important advantages of mechanical cleaning methods are the abundance of research on the techniques and the fact that they are not dependent on the fouling chemical composition.

Takeaway. Based on the preceding review of research related to the different cleaning methods for fouling mitigation, the hydroblasting technique shows many operational, environmental and economic advantages when compared to the other methods, all of which depend on the use of chemicals or nanotechnology. The merits of hydroblasting are summarized:

1. Unlike the chemical and nanotechnology fouling mitigation methods, hydroblasting results in no hazardous wastes requiring special treatment before disposal.
2. From an operational standpoint, hydroblasting is safe for both personnel and equipment because there is no risk on the boiler components due to corrosive chemical additives or nanoparticles, making it the best method for mitigation of fouling.
3. Hydroblasting appears to be the most economic technique, as it can be remotely auto-operated, which means fewer labor hours. Also, the water can be reused after being filtered, which decreases operational costs when compared with the chemical or nanotechnology mitigation methods.

The great challenge to the applicability of the hydroblasting technique in a fire tube boiler is ease of access; however, this can be overcome by increasing the clearances between tubes in the bundle. Also, having an inline tube bundle configuration (rather than a staggered pattern arrangement) can contribute to solving the problem.

Manufacturer preference for compact boilers must be revised and discussed to find the most appropriate design that guarantees the easiest accessibility to the outer surfaces of the tube bundle. Also, boiler feedwater treatment programs must be adjusted to keep the water side of a fire tube boiler as clear as possible. Typically, these programs are not satisfactory to delay or mitigate water-side fouling. The quality requirement for fire tube boiler feedwater from different practices and manufacturers is usually lower than that required for water tube boilers; this could cause problematic, complicated deposits with thicker layers. HP

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